Brief history the evolution of Soviet air defense systems

Following the detailed description of the different air defense systems it is worth to summarize the race between the 'swords and shield'. The point of this section is understanding the driving force of the evolution considering both the type of targets and defensive equipment on them.

Let's start with homeland air defense (PVO) systems.

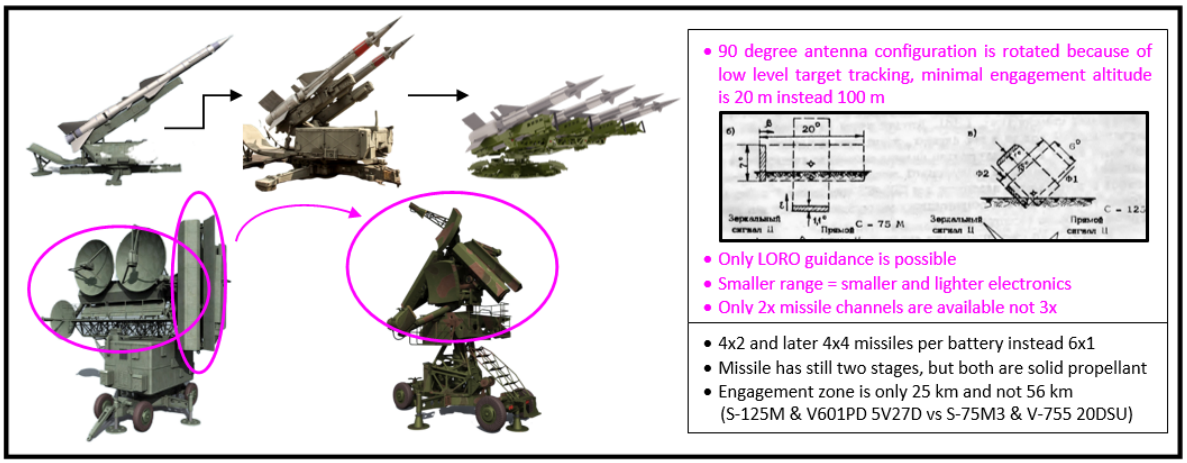
1. **S-25/S-25M Berkut/Sosna (SA-1 Guild).** It was created against long range intercontinental bombers (B-36, B-47, B-52) with lots of target channels. It had 20 (!) target channels per regiment (system) but this capability demanded so huge infrastructure which made static the system concerning both tits location and the direction of the engagement zone. It was way too expensive to build them elsewhere than around Moscow. Another factor was that less important targets simply did not need so many target channels and missiles.

2. Something more scalable, cheaper and easier deployable system was needed with 360 degree launch capability. This became the **SA-75/S-75M Divna, Desna/Volkhov (SA-2 Guideline)** family with a single target channel/battery but it could be set any direction that single target channel. It was far cheaper and flexible with similar engagement range to S-25/S-25M.

   In the Vietnam conflict it became evident the USA could jam them in many ways to reduce their effectiveness especially against fighters and strike fighters. In 1966 71% of the guidance with Dvina SAMs were performed with auto target tracking while in late period of 1967 this dropped to 4%. Only manual target tracking could be applied with three point guidance.

   Regardless of continuous development both the SA-75 and S-75M were inadequate against low level targets. A shorter range low level capable system was needed.

3. The **S-125 Neva (SA-3 Goa)** had such low level capability which was lacked by the S-25 and SA-75/S-75 families. Against low level targets detection range generally is smaller because of the terrain and curvature of the Earth. Therefore, it was pointless to create (in that time) a longer range system with low level capability as main goal especially when another goal was to make it cheaper the new system.



The Neva is literally a downscaled and simplified S-75M Volkhov for short range and low level goals. The antenna configuration is different, the LORO guidance type is the only available for the Neva. It had more missiles ready to launch even at initial configuration 4x launchers and 2x missiles on each which later increased to 4x4 missiles. The missile still had solid booster stage, but the main engine

was changed to solid propellant which made easier handling the missiles. The smaller missile had better turning capability.

But the Neva could be jammed with (almost) the same methods as the previous SAM system. Using in combination with SA-2 area defense and denial was still not possible. A very long range SAM was needed but with different guidance principle and antenna because of know jamming methods.

4. **S-200 Angara/Vega/Dubna (SA-5 Gammon)** family. It had huge range, Angara had "only" 150 km, but later upgraded Vega-M had 250 km, and last iteration the Dubna had 300 km. Finally, the Soviet Union had area denial capability.

   The S-200 was immune to every jamming type which were usable against S-25/75/125 because of the monopulse CW radar + SARH guidance. Its maximal target speed made usable against the AGM-28 (both in high level high speed and low level low speed) and the M3.0 capable AGM-69 SRAM. Because of the demanded huge range liquid propellant had to be used for the main engine which was a step backward comparing to S-125M Neva. The huge missile needed a booster stage. The system had an exceptionally large minimal engagement distance 17 (!) km.

5. **S-300/400 (SA-10 Biryusa, SA-20 Favorit/SA-21 Triumf)** family. Then came the BGM-109 Tomahawk and the AGM-86 ALCM as very low level threats. These could be launched from 1000 km+ distance and were able to fly only at 30 meter altitude. They simply made obsolete all the previous SAM systems.

   The goal was creating a successor SAM system which is capable to destroy these targets at very low level (30 m or lower) even targets incoming in massive scale. Besides the first goal the SAM should retain (at least some) area denial capability, but this goal could be achieved only by incremental development. The goal in longer perspective was replace the S-25M, S-75M and S-125M and even the long range S-200 family with an S-300 variant.

   This took 30 (!) years from the first deployed S-300PT/SA-10A (1978) to the first S-400/A-23 (2007). Even today (2020) the S-300PS are still is service so far only the PT and PT-1 variants have been replaced with more advanced S-300/400 or with S-350 Vityaz.

   The system uses SAGG guidance (only the PT-1/PT used pure radio command). The S-400 will have the 40N6 active radar guided missile which can have over the horizon capability in case other assets can provide target track data in mid-course phase. Engagement range against some targets can be 380 km.

Evolution of army air defense.

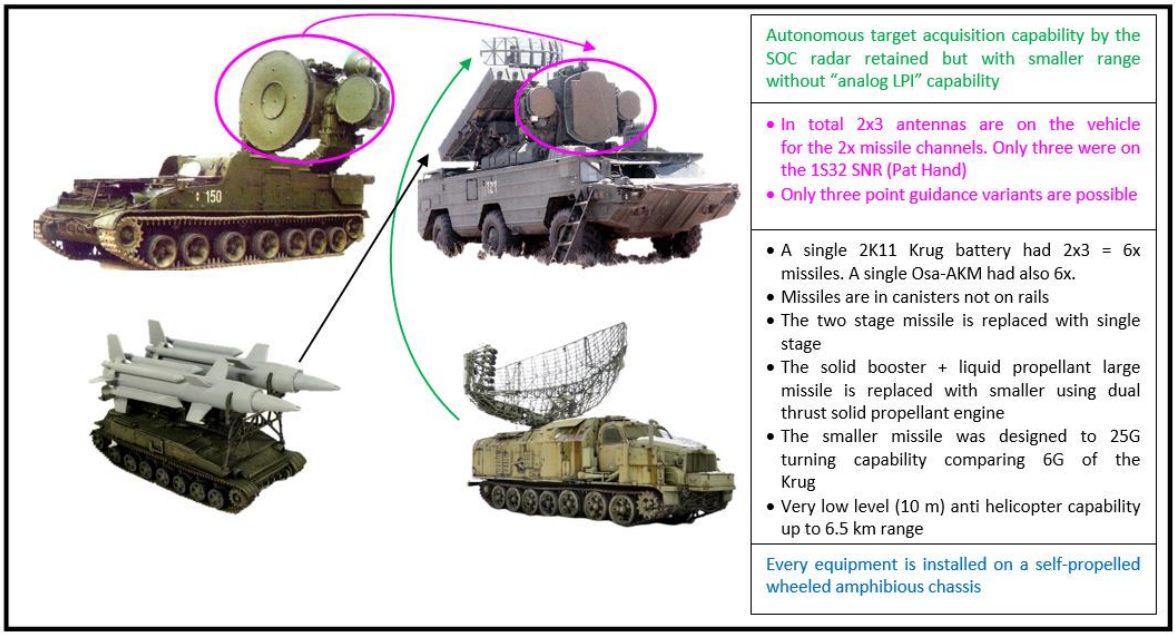
1. **2K11 Krug family (SA-4 Ganef).** It was the first fully mobile radar guided SAM system. It had a very complex antenna system with a missile with very weak maneuvering capability. The system had only single target and single missile channel. Because only a single missile could be guided it was not even possible to make harder the defeat by maneuverability for the target with evasive maneuvers. Regardless the large engagement zone (and the "analog LPI feature) the long cycle time and single missile guidance capability meant its firepower was quite small considering the cost of the system.

The missile was more user friendly comparing to PVO SAMs because it used kerosene as fuel and not the two component very toxic fuel of as the S-25, SA-75/S-75M and S-200 families.

The Krug got the new monopulse antenna technology (with still using radio command guidance) and used very narrow beam which provided quite a good ARM immunity against the Vietnam era AGM-45 Shrike and AGM-78 Standard.

2. **9K33 Osa family (SA-8 Gecko).** Based on the experience of Middle East conflicts it was evident more missiles are needed with more target channels and better turning capability against fighters and strike fighters. It many cases is better to have more smaller range SAMs then a few long range ones.

   Because the Krug has been developed it was the base of the development. The 9K33 Osa is a scaled down 2K11 Krug without the "analog LPI" capability. While the Krug had many self-propelled elements every equipment of the Osa was installed on a single self-propelled vehicle.



The Osa got +1 missile channel comparing to Krug it could guide two missiles on a single target. The two missile channel capability demanded the lots of independently steered antenna which resulted the most complex mechanically steered antenna system ever was put into service. The Osa inherited by its design from the Krug the good ARM immunity against the Vietnam era AGM-45 Shrike and AGM-78 Standard because of the very narrow beams.

The single 9K33 vehicle retained the autonomous target acquisition capability but with smaller range according the engagement zone.

The Osa got a smaller but more agile missile. It Vietnam because of jamming in most of the cases only worst three point guidance was possible. Because of this Osa can perform **only** three point guidance variants. The used jamming type in Vietnam does not have effect on missile kinematics.

The missile was designed around three point guidance limitation keeping mind the typical targets in Vietnam were fighters and strike fighters. They are much more maneuverable than strategic bombers. The missile was designed with 25G max. turning capability which is enough even against later coming 4th generation fighters. The Osa-AKM was usable even against very low flying helicopters up to 6.5 km range.

Because of the smaller range it was not required a separated booster stage moreover, the missile got a dual thrust rocket engine which provided very good range considering the small size of the missile. This also meant smaller minimal engagement range.

Only problem it took very long to develop it the 2K12 Kub (SA-6) reached the manufacturing earlier.

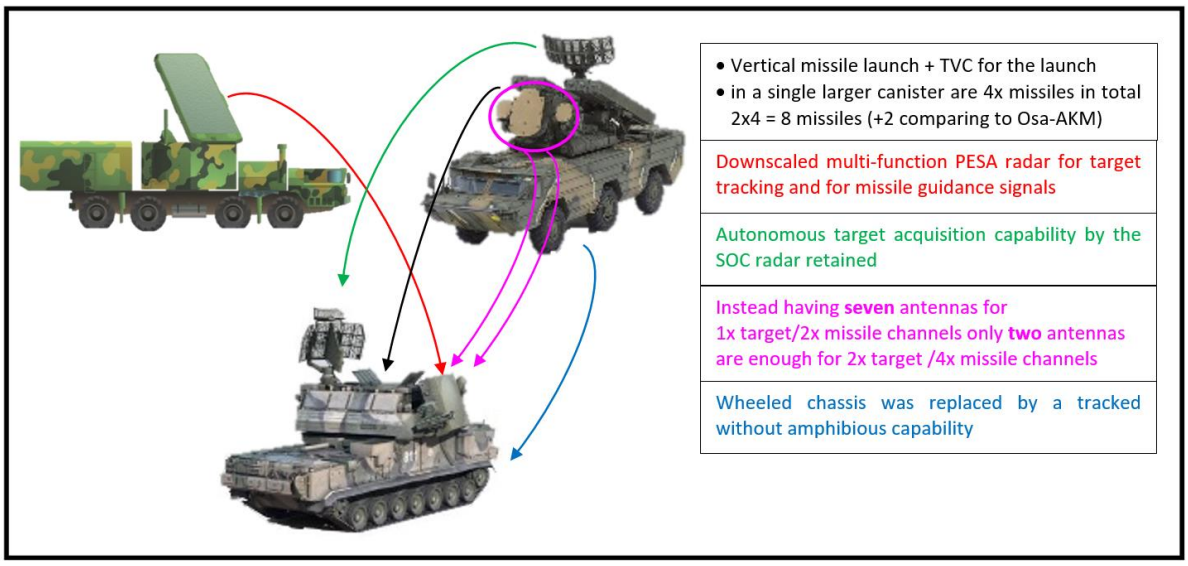
3. **2K12 Kub (SA-6 Gainful)** family. It was completed before the 9K33 Osa regardless its development started later. It got CW fire control radar with monopulse technology and SARH guidance similarly to S-200 family. The 2K12 was scaled down in size according to the mobility and deployment requirement of the army. Because of this on a single vehicle was mounted both the target acquisition radar and the fire control radar. (Which was not so good idea therefore it got later the IADS data link connection.)

   The Kub had larger range comparing to 9K33 Osa (almost double both in range and altitude) and it was immune the jamming methods were used in Vietnam. The narrow beam fire control radar made better protected against AGM-45/78 than the Dvina was in Vietnam.

   The missile had 15G turning capability which was much better comparing to Dvina's missile used in Vietnam. The missile got solid-propellant ramjet rocket engine which made much easier to handling comparing to liquid-propellant missiles of the 2K12 Krug.

   The 2K12 was planned to reach sooner the service than the 2K11 Krug but the development issues of the CW radar and the new ramjet rocket engine delayed the manufacturing.

4. **9K331 Tor-M1 (SA-15 Gauntlet).** Following the development of the 9K33 Osa became evident to provide more target or missile channel is not possible with mechanically steered antennas. A new solution had to be found. Luckily the S-300 was a good base for this which got a PESA fire control radar. The Tor-M1 is essentially scaled down S-300 the case is similarly the Krug--->Osa design.



   The 9K331 Tor-M1 has a single PESA fire control radar (and small additional radar for initial) missile guidance comparing to the lots of antennas of the 9K33 Osa. The Tor-M1 vehicle also retained the autonomous target acquisition capability but with smaller range according the engagement zone comparing to the S-300.

   Comparing to 9K33 Osa-AKM it has 8x missiles and not 6x which was requested for Osa-AKM. (The first Osa had only 4x missiles.) The scaling down meant it got less target and missile channels than

the S-300 (6x target /12x missile) but the 2x target and 4x missile channels are twice as much what the 9K33 Osa had.

The Osa was enough good against TOW missile capable helicopters but the 9K331 Tor-M1 set the bar even higher. The engagement range was increased to 7 km against helicopter, the engagement altitude against planes airplanes increased to 6 km to 12 km range.

5. **2K22M Tunguska (SA-19 Grison).** The appearance of the AH-64A + AGM-114 missile with 8 km maximal engagement range demanded a new kind of SHORAD system to replace the very short ranged ZSU-23-4 self-propelled gun and the Strela-1/10 SHORADs with less about 5 km range. The new system also should be capable to engage airplanes better. The system has only a single target channel, but it combined the anti-aircraft gun and the missiles on the same platform. The 2K22M has 8 km maximal engagement range against low flying helicopters with the missiles. The effective range of the gun depending on the target parameters is 3-4 km.

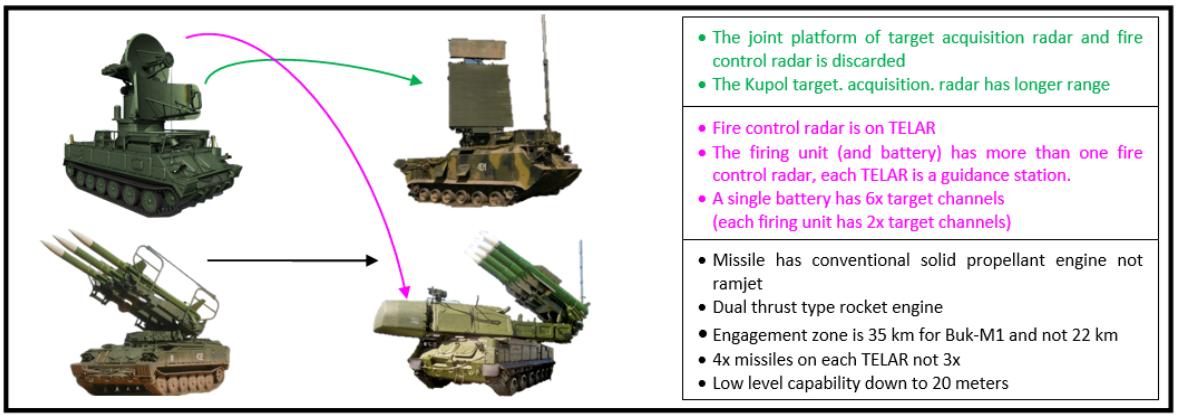
   (The regiment level air defense units were planned to equip with 2K22M the division level units with 9K331, but the Cold War ended before this could be done.)

6. **9K37M Buk-M1 (SA-11 Gadfly).** Both on army and army group level was needed a new kind of SAM to replace the aging 2K11 Krug because of the new kind of threats (4th generation fighters, new anti-radiation missiles, faster and more advanced ballistic missiles such as Pershing II, etc.).

   Regardless the strong political pressure (from Dmitriy Ustinov) the army disliked a joint SAM program and resisted but eventually they had to accept it. This was the Buk-M1.

   The Buk-M1 is a strongly upgraded 2K12 Kub-M3. It uses basically very similar CW+SARH radar and guidance but with a larger missile. The Buk-M1 did not get a PESA type fire control radar therefore the quantity of fire control radars had to be increased. Instead having a single fire control radar per battery, a missile launcher is combined with a fire control radar which it made a TELAR.

   The missile got a dual thrust rocket engine to have considerably larger range. The Buk-M1 became the new army level air defense system.



7. **9K81 S-300V Antey (SA-12B).** The S-300P/F was good both for the largest ships (the smaller ones got the Buk-M1) for the navy as well as for the PVO.[1]

   Because of the fear of Pershing II the army needed a two stage missile to have a real effective range against very fast ballistic missiles. Because of this the S-300V became a SAM system which is used exclusively by the army. Its radar looks similarly to S-300P because of the similar base technology

[1] *The PVO was the luckiest branch because the S-300P family was able to replace all its previous SAM systems.*

but the equipment is different. The S-300V is literally a mobile version of the American AEGIS system but a single battery has only one 9S32 Grill Pan radar. A single S-300V battery has only 90 degree launch arc not 360 degree because of the Grill Pan radar. While the S-300 family uses (with two exceptions) SAGG guidance the S-300V uses RCG + terminal SARH.

The evolution is different from the point of view of helicopters:

1. Appearance of the first "combat" helicopters. They were literally armed transport helicopters with guns or unguided rockets under their pylons. Max range of their weapons is about 2 km. The first generation of MANPAD the 9K32 Strela-2 (SA-7 Grail) was very weak and lacked all aspect capability. But the 2-2.5 km effective range of the ZSU-23-4 Shilka was enough to make a bad day for Joe in case a helicopter meets with the radar guided AAA.
2. Joe is thinking something should be done with the dangerous Shilka. Born of the dedicated AH-1 combat helicopter with 4 km range BGM-71 TOW. If the reconnaissance is good now the helicopter has longer "spear" than the Shilka. Joe is very happy.
3. Now Ivan is thinking. The range of TOW missile is too big, missiles are needed to counter it. The EO/IR SHORAD was born. Strela-1 (SA-9 Gaskin) got EO and later the Strela-10 got EO/IR guided missile which can be launched head aspect with 4-5 km range even at low level targets. The ground and sky clutter are issues and Strela-10 was not all aspect in IR mode, but these is better than nothing.

   Meanwhile the MANPADs became more and more advanced, arrival of the 9K34 Strela-3 (SA-14 Gremlin) in '70s, the 9K310 Igla-1 (SA-16 Gimlet) and the 9K38 Igla (SA-18 Grouse) in early and mid '80. Joe was not so happy anymore...
4. Joe looked very sharply on the MANPADs and SHORADs and realized something. The operator must see visually the target to aim and launch a missile. The solution; let's fly at night because Ivan is not Superman he can't see at night with naked eye.

   The answer was the AH-64A equipped with FLIR tower + night vision for the operators, the combat helicopter is armed with laser guided 8 km range AGM-114 Hellfire anti-tank guided missile. This new "spear" outranged even the 9K33 Osa-AKM.

   Because of the widespread usage of the EO/IR missiles flare dispensers are now part of the base equipment. Just for sure against Osa-AKM radar warning receiver is also part of the base avionics package. Joe is very happy now.
5. Ivan is not so happy about the good mood of Joe. Damn capitalists...! With the last effort of the Soviet Union before the collapse developed the 2K22M Tunguska (SA-19 Grison) with 8 km range missile and just for sure with guns in case of lack of missile and close targets.
6. Joe's legs are now shaking again but he had a good idea. Ok, it is time to act as a good sniper I must be hidden. I can hide behind a hill and only my "intelligent eyes" will be above the terrain. I can throw my missiles to their targets using with my advanced new equipment.

   The answer was the AH-64D equipped with a mm wavelength LPI fire control radar dome above the main rotor. The new radar guided AGM-114L missile can be guided simultaneously with the electronically scanned radar.

This was the last step in the evolution. To counter this attack profile of a helicopter such kind of SAM system is needed which can detect the very small radar dome and can guide such way the missile which detonates above the target. Which is just behind an obstacle and it is in ground clutter.

Besides the range and day/night factors other options are available for self-defense. From the point of view of the helicopters again:

1. Against MANPADs helicopters got flare dispensers but only with Mark I eyeball (naked eye) can detect the launch and provides defense only for some second a single flare decoy. Luckily the first generation of amplitude modulated (AM) [2] IR seekers were very vulnerable to flares. Joe is only more or less happy.
2. The hot brick jammers can provide continuous "shield" against the Strela-2 and similar old MANPADs.

   (But only if Joe flies with helicopter because on most of airplanes because of the high drag of the system such kind of jammers cannot be mounted.

   Besides these kind of active jamming infrared suppressors/heat dissipators also could be mounted on the exhaust of the gas turbine to reduce the IR signature of the helicopter.[3]

   Joe is very happy now.
3. But Ivan does not stop and develops the frequency modulated (FM) IR seekers which are less vulnerable and later became immune against the hot brick jammers.

   Joe inverts the problem and instead continuous jamming equips the helicopters with a 360 degree coverage sharp eye which can detect the MANPAD launches. These "eyes" are the MAWS (missile approach warning systems).

   Relying only on naked eye is not the only option and the launch of flare decoys can be automatic. The shield is virtually continuous because of the sort reaction time of the MAWS. Against not so advanced IR seekers the chance of defeat by flare is high. Joe is happy now.
4. Ivan rolled up his sleeve again and designed the dual band IR seekers which in theory immune to flares. Stakes are now even higher. Joe is playing now hard. He simply blinds the IR seeker with DIRCM[4] as a 24 carat diamond does with many brides.
5. Today now IADS is more and more widespread with advanced MANPADs. In the near future the most advanced AH-64E will fly along UAVs as recon units and expandable follower as well as other helicopters.[5]

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2 *http://www.mediafire.com/file/nq6i1ja0ds9qqi4/Histoy_of_the_Electro-Optical_Guided_Missiles.pdf*

3 *https://aviation.stackexchange.com/questions/21277/what-is-a-heat-dissipater-and-how-does-it-work*

4 *https://www.youtube.com/watch?v=7qqQuwRX-ps*
https://elbitsystems.com/product/directed-ir-countermeasures-2/

5 *https://youtu.be/KJClODcNkC4*
https://youtu.be/mrvZWaB7_1E

Double digit SAMs, terminology issues

In the English sources many times can be read such term as "double digit" air defense systems. This came from the NATO designations of certain group or **radar guided** SAMs. The "single digit" radar guided SAMs are the SA-2/3/4/5/6/8. They are the Cold War manufactured systems with a single target channel per vehicle or battery.[6] The "double digit" SAMs are which have multiple target channels by their design or the structure of a battery (SA-11/Buk-M1.) These are the SA-10/11/12/15/17/20/21/23 SAM systems. The SA-19/2K22M Tunguska is exceptional because it has single target channel, but it is so advanced comparing its predecessors it is also int this different category. Considering early '90s regardless its development era it is a post-Cold War system because of its delayed manufacture.

The problem with "double digit" term or label that is a bit misleading. If we strictly consider only the numbers both IR/EO guided SHORAD and MANPADs are also falling into the category even Cold War systems such as the SA-14/16/18 MANPADs which were all manufactured during the '70s and '80s.

The one value difference between the SA-9 and SA-10 does not explain anything because they are totally different kind of air defense systems. Considering the applied technology and the role of the different air defense systems the SA-xx denomination system is not so useful. The chart below shows the designation of the systems and their main guidance type. Some radar SAMs had the option for optical target tracking with radio command guidance see this in their detailed description.

PVO = homeland air defense, SV = army, * S-300PT RCG, S-400 with 40N6 is active radar

US designation/NATO code	Russian designation and name	Branch	Guidance
SA-1 Guild	S-25 Berkut, S-25M Sosna	PVO	RADAR, RCG
SA-2 Guideline	SA-75 Dvina, Desna, S-75/S-75M Volkhov	PVO	RADAR, RCG
SA-3 Goa	S-125 Neva	PVO	RADAR, RCG
SA-4 Ganef	2K11 Krug	SV	RADAR, RCG
SA-5 Gammon	S-200A/V/D Angara/Vega/Dubna	PVO	RADAR, SARH
SA-6 Gainful	2K12 Kub	SV	RADAR, SARH
SA-7 Grail	9K32 Strela-2	SV	IR (MANPAD)
SA-8 Gecko	9K33 Osa	SV	RADAR, RCG
SA-9 Gaskin	9K31 Strela-1	SV	EO (SHORAD)
SA-10 Grumble	S-300PT, S-300PS Biryusa/ S-300 PMU Volkhov-M6	PVO	RADAR, SAGG*
SA-11 Gadfly	9K317 Buk, 9K37M Buk-M1	SV	RADAR, SARH
SA-12 Gladiator/Giant	S-300V Antey[7]	SV	RADAR, RCG+SARH
SA-13 Gopher	9K35 Sztrela-10	SV	IR/EO (SHORAD)
SA-14 Gremlin	9K34 Sztrela-3	SV	IR (MANPAD)
SA-15 Gauntlet	9K330 Tor, 9K331 Tor-M1	SV	RADAR, RCG
SA-16 Gimlet	9K310 Igla-1	SV	IR (MANPAD)
SA-17 Grizzly	9K37M2 Buk-M2	SV	RADAR, SARH
SA-18 Grouse	9K38 Igla	SV	IR (MANPAD)
SA-19 Grison	2K22 Tunguska	SV	RADAR, RCG
SA-20 Gargoyle	S-300PM/PMU-1 Volhov-M6M. S-300 PM2/PMU2 Favorit	PVO[8]	RADAR, SAGG
SA-21 Growler	S-400 Triumf	PVO	RADAR, SAGG*
SA-22 Greyhound	96K6 Pantsir-S1	PVO	RADAR, RCG
SA-23 Gladiator/Giant	S-300VM Antey-2500	SV	RADAR, RCG+SARH
SA-24 Grinch	9K338 Igla-S	SV	IR (MANPAD)
SA-25	9K333 Verba	SV	IR (MANPAD)

[6] *SA-1 is exceptional because the huge amount of target channels was provided with brute force. With a totally static design it was possible to install so many equipment and such two fast-rotating radars which made possible the multiple target channel per sites.*

[7] *The V1 variant was called S-300V1 Antey-300 because it could be used only against 300 km BMs.*

[8] *The PVO was disbanded in 1998 but for easier role designation I used for systems following this organizational change.*

The export variant of the SAM systems outside the WPACT countries got different names these are the following:

- S-75M Volga (SA-2)
- S-125 Pechora (SA-3)
- 2K12 Kvadrat (SA-6)
- 9K37M Gang (SA-11)